

Fluid, electrolytes and nutrition*

Simon Allison

Clinical Nutrition Unit, University Hospital, Nottingham, UK

Abstract

There is a close relationship between nutrition, metabolism, and water and electrolyte balance during ingestion, digestion, absorption and metabolism of nutrients. It is clinically important to consider not only external balance, but also internal balances between the intravascular and extravascular portions of the extracellular fluid (ECF), between the ECF and the gut during daily flux, and between the ECF and intracellular fluid, since all these balances may be affected by disease, treatment and nutrition. Doctors' knowledge of fluid and electrolyte pathophysiology is often as poor as their knowledge of nutrition. Both subjects require a major educational effort.

Introduction

When animals emerged from the sea onto land, they faced several problems including the development of their own internal sea of extracellular fluid in which their cells could bathe in a "milieu interieur" of constant composition. The body fluid compartments are maintained not only by appropriate intake of water and electrolytes but also by renal excretion and by metabolically dependent control mechanisms that control distribution within the body. It is of clinical importance, therefore, to consider not only the external balance between the body and its environment, but also the balance between the various internal compartments whose equilibrium can be upset by disease. The subjects of fluid balance and nutrition have a clear affinity, since the intake of nutrients by natural or artificial means is inseparable from that of water and electrolytes. They are also closely linked in the processes of digestion, absorption and intermediary metabolism.

Surveys have shown a poor understanding of nutrition among doctors. Two surveys (1, 2) by the present author showed an equally poor understanding of fluid and electrolytes, particularly among junior doctors, who are responsible for 95% of the fluid prescriptions in hospital. In a few cases, the error is to give insufficient fluid, but in the majority of cases overloading with salt and water is the major problem.

*The Gunnar Levin Lecture was presented at the annual meeting of the Swedish Society of Medicine, November 28, 2002.

Oedema, albumin and nutritional support

A retrospective survey (3) of patients referred for artificial nutritional support after surgery or from the intensive care unit found that the majority had oedema, with an average fluid overload of 10 kg, accompanied by hypoalbuminaemia. Diuretics were given in cases where venous pressure was elevated, but in those with oedema and interstitial overload combined with a low venous pressure due to continuous plasma losses, 200–400 ml of 20% salt-poor albumin was infused before any diuresis was possible and diuretic sensitivity was restored. It should be emphasized that albumin was infused to restore effective blood volume only, since there is no evidence supporting the use of albumin to treat hypoalbuminaemia per se. As excess salt and water was removed, the serum albumin rose by 1 g l^{-1} for every 1 kg loss of fluid, showing reversal of the dilutional effects of previously administered crystalloids.

It was unfortunate that the Cochrane systematic review (4) muddled the issues surrounding albumin, perhaps because its authors were epidemiologists and statisticians without experience of the pathophysiology of the critically ill. Albumin normally leaks from the capillaries at a rate of 5% of the total plasma albumin per hour (10 times its rate of synthesis) and is returned to the circulation via the lymphatics (5). After major surgery the escape rate increased 3–5-fold (6, 7), returning to normal over 10 days. It is argued, probably correctly, that because of the increased escape rate and its expense, the use of albumin solutions for acute resuscitation is unjustified, and crystalloids and artificial colloids

are preferred despite the fact that they inevitably cause a salt overload that has to be excreted later (see below). Albumin may still have a place, however, in some acute situations, e.g. meningococcal septicaemia in children. In the post-acute phase, however, 5–10 days later, albumin seems to be better retained within the circulation and, being low in salt, does not exacerbate oedema (5, 8). Another corollary of the above observations is that albumin is more a marker of inflammation causing redistribution and of dilution with crystalloids than of nutritional status. Its return to normal after illness may be delayed, however, by malnutrition and accelerated by nutritional support (9).

Fluid overload and gastrointestinal function

In the above study of patients referred for nutritional support it was also noted that, with clearance of oedema, there appeared to be faster return of gastrointestinal function. This observation led to studies (10) of patients undergoing hemicolectomy for cancer, who were randomized to receive a postoperative intravenous regimen of 3 litres of water and 150 mmol of sodium daily intravenously, or a restricted prescription of 2 litres of water and 70 mmol of sodium. Solid- and liquid-phase gastric emptying were measured isotopically on the fourth day. In all of the restricted group gastric emptying was nearly normal by the fourth day in all cases, whereas it was prolonged 2- or 3-fold in the high fluid intake group. The restricted group also ate earlier, had fewer complications and were discharged 3 days earlier than the high fluid intake group. Salt and water excess is not therefore harmless and may also be associated with other complications (11, 12).

Response to injury and starvation

It has been known since the beginning of the twentieth century that surgery, anaesthesia and injury are associated with impaired ability to excrete a salt and water load. Indeed, Moore (13) coined the terms “the sodium retention phase of injury”, to describe the first few days, followed by the “diuresis phase” during recovery, when the capacity to excrete salt and water returns to normal. Many doctors fail to allow for this phenomenon.

With prolonged starvation and weight loss (14) the extracellular fluid (ECF) volume assumes a higher proportion of the body weight since it does not shrink at the same rate as the fat and fat-free

mass. The capacity to excrete a salt and water load is also diminished, resulting in “famine oedema”, as well as refeeding oedema once nutritional intake is restored.

Studies in normal subjects

It is also insufficiently recognized that even normal subjects excrete saline rather inefficiently, which is teleologically understandable when one considers that, during evolution, the mammalian body has been exposed to wide variations in water availability and also to a low salt supply, but not until recently to a high sodium intake. Human physiology is therefore admirably evolved to deal with high and low water consumption and low salt intake, but not with high salt intake. Changes in water intake stimulate the osmoreceptors with secretion or switching off of antidiuretic hormone (ADH), causing a wide range of urinary concentration or dilution. Through volume receptors, salt depletion stimulates the renin–angiotensin aldosterone system to signal the kidney to retain salt. Hypovolaemia also stimulates ADH, overriding the osmoreceptors, so that in the presence of hypovolaemia it is easy to induce hyponatraemia by the administration of hypotonic fluids. A series of studies on normal subjects (15, 16) showed that, whereas 5% dextrose is excreted within 2 h of its infusion, two-thirds of a saline load is retained even 6 h after its infusion, with persistence of dilutional hypoalbuminaemia. Atrial natriuretic peptide (ANP) levels rose abruptly during the infusion of both dextrose and saline, but fell to baseline at the end of the infusion despite the residual sodium overload of 300 mmol. ANP, therefore, does not appear to play an important role in the excretion of an acute saline load, which depends rather on a permissive switching off of the renin–angiotensin aldosterone system. It should also be remembered that saline is unphysiological, since its ratio of chloride to sodium is 1:1, whereas that in plasma is 1:1.38. It is therefore easy to induce a hyperchloraemic acidosis. One study compared the capacity of normal subjects to excrete a saline versus a Ringer lactate load (17), the latter having a more physiological chloride:sodium ratio. Despite Ringer lactate having a lower sodium content, more sodium was excreted in the 4 h after infusion than following saline, suggesting that slow excretion of chloride ions may play a part in the delayed excretion of

saline. Chloride ions have also been shown to reduce the glomerular filtration rate (18).

Flux through the gastrointestinal tract

The flux of fluid through the gastrointestinal tract is large, with 8–9 litres of gastrointestinal secretions and fluid intake passing through the duodenum daily. By the time intestinal contents reach the ileocaecal valve, this is reduced to 1500 ml, and to 150 ml during transit through the large bowel, salt and water absorption being linked to carbohydrate in the jejunum and to short-chain fatty acids in the colon. In gastrointestinal disease, or with fistula and short bowel, large deviations in fluid and electrolyte balance may occur and require appropriate correction and maintenance. Clinicians should therefore know the electrolyte concentrations of such fluids, and allow for this when prescribing parenteral nutrition in such cases.

Intracellular versus extracellular spaces

Through the adenosine triphosphate (ATP)-dependent sodium pump, sodium ions are largely confined to the ECF, providing its main osmotic element. Potassium ions are retained within the cell to neutralize the negative charges on protein (Donnan equilibrium) and also to associate with glycogen. In critically ill patients the sodium pumping mechanism may fail, leading to the “sick cell syndrome” (19) and accumulation of sodium within the cell. This process is exacerbated by poor tissue perfusion and oxygenation as well as by toxæmia and metabolic events. A study on muscle biopsies from critically ill patients confirmed this entity (20). Some of the present author’s work (21) has shown that treating underlying sepsis, improving tissue perfusion, and administering insulin, glucose and potassium may help to reverse the sick cell syndrome, raise the plasma sodium, and cause a sodium and water diuresis. His studies also showed the effect of insulin in reducing protein catabolism (22–24), which has since been confirmed by others. Recent data (25) showing improved outcome using insulin to maintain normoglycaemia in patients on the intensive care unit may also be explained by insulin’s other effects on protein metabolism and cell membrane function. Cellular metabolism may be thought of in terms of a “metabolic tide” in which, during starvation or catabolic illness, glycogen and protein are broken down to glucose and amino acids, which are then

released by the cell with potassium. In severe cases, sodium pumping may also be impaired. With refeeding there is cellular uptake of substrates with synthesis of protein and glycogen, accompanied by reuptake of potassium and phosphate and by enhanced sodium pumping. This may even lead to ECF hypokalaemia and hypophosphataemia unless these electrolytes are supplemented.

References

1. Lobo DN, Dube MG, Neal KR, et al. Problems with solutions: drowning in the brine of an inadequate knowledge base. *Clin Nutr* 2001; 20: 125–30.
2. Lobo DN, Dube MG, Neal KR, et al. Perioperative fluid and electrolyte management: a survey of consultant surgeons in the United Kingdom. *Ann R Coll Surg Engl* 2002; in press.
3. Lobo DN, Bjarnason K, Field J, et al. Changes in weight, fluid balance and serum albumin in patients referred for nutritional support. *Clin Nutr* 1999; 18: 197–201.
4. Cochrane Injuries Group Albumin Reviewers. Human albumin administration in critically ill patients: systematic review of randomised controlled trials. *Br Med J* 1998; 317: 235–40.
5. Allison SP, Lobo DN, Stanga Z. The treatment of hypoalbuminaemia. *Clin Nutr* 2001; 20: 275–9.
6. Fleck A, Raines G, Hawker F, et al. Increased vascular permeability: a major cause of hypoalbuminaemia in disease and injury. *Lancet* 1985; i: 781–4.
7. Anderson JA, Lobo DN, Lawes SC, et al. Sequential changes in serum albumin, C-reactive protein and transcapillary escape rate of albumin in patients undergoing major abdominal surgery. *Clin Nutr* 2002; 21(Suppl 1): 29.
8. Allison SP, Lobo DN. Debate: albumin administration should not be avoided. *Crit Care* 2000; 4: 147–50.
9. Bastow MD, Rawlings J, Allison SP. Benefits of supplementary tube feeding after fractured neck of femur: a randomised controlled trial. *Br Med J* 1983; 287: 1589–92.
10. Lobo DN, Neal KR, Perkins AC, et al. Effect of salt and water balance on recovery of gastrointestinal function after elective colonic resection: a randomised controlled trial. *Lancet* 2002; 359: 1812–8.
11. Starker PM, Lasala PA, Askanazi J, et al. The influence of preoperative total parenteral nutrition upon morbidity and mortality. *Surg Gynaecol Obstet* 1986; 162: 569–74.
12. Gil MJ, Franch G, Guirao X, et al. Response of severely malnourished patients to preoperative parenteral nutrition: a randomised clinical trial of water and sodium restriction. *Nutrition* 1997; 13: 26–31.
13. Moore FD. *Metabolic care of the surgical patient*. Philadelphia, PA: Saunders; 1959.

14. Keys A, Brozek J, Henschel A. The biology of human starvation. Minneapolis, MN: University of Minnesota Press; 1988.
15. Lobo DN, Stanga Z, Simpson JAD, et al. Dilution and redistribution effects of rapid 2-litre infusions of 0.9% (w/v) saline and 5% (w/v) dextrose on haematological parameters and serum biochemistry in normal subjects: a double-blind crossover study. *Clin Sci* 2001; 101: 173–9.
16. Lobo DN, Myhill DJ, Stanga Z, et al. The effect of volume loading with 1 litre intravenous infusions of 0.9% saline and 5% dextrose on the renin angiotensin system (RAS) and volume controlling hormones: a randomised double crossover study. *Clin Nutr* 2002; 21(Suppl 1): 9–10.
17. Reid F, Lobo DN, Williams RN, et al. (Ab)normal saline and physiological Hartmann's solution: a randomised double-blind crossover study. *Clin Sci* 2003; 104: 17–24.
18. Wilcox CS. Regulation of renal blood flow by plasma chloride. *J Clin Invest* 1983; 71: 726–35.
19. Fleck CT, Singh CM. Hyponatraemia and sick cells. *Br J Anaesth* 1973; 45: 976–94.
20. Campbell IT, Green CJ, Jackson MJ. Muscle glycogen and electrolyte concentrations in multiple organ failure. *Proc Nutr Soc* 1998; 57: 111A.
21. Hinton P, Allison SP, Littlejohn S, Lloyd J. Electrolyte changes in burn injury and the effect of treatment. *Lancet* 1973; i: 218.
22. Hinton P, Allison SP, Littlejohn S, Lloyd J. Insulin and glucose to reduce catabolic response to injury in burned patients. *Lancet* 1971; i: 767.
23. Woolfson AMJ, Heatley RV, Allison SP. Insulin to inhibit protein catabolism after injury. *N Engl J Med* 1979; 300: 14–7.
24. Martinez-Riquelme AE, Allison SP. Insulin revisited. *Clin Nutr* 2003; 22: 7–15.
25. van den Berghe G, Wouters P, Weekers F, et al. Intensive insulin therapy in the critically ill patients. *N Engl J Med* 2001; 345: 1359–67.

Simon Allison
Clinical Nutrition Unit
University Hospital
Nottingham, UK
Tel/Fax: +44 115 919 4427
E-mail: simon.allison@mail.qmcuh-tr.trent.nhs.uk